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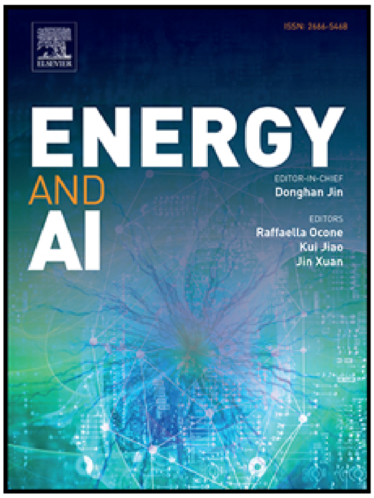

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Energy and AI

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Intelligence is an attribute of human beings, it is an understanding, analyzing and decision-making process based on people's perception of the world. Intelligence is enhanced by the interactions among different human beings and the physical world, and becomes the driving force for the development of our traditional society consisting of a physical space and a human social space. The rules of our traditional society are also formed and developed during such interactions.

With ever increasing influence of big data, cloud computing, machine learning, internet of things and other technologies together with various intelligent devices, the society is becoming "a trinary space" including not only the physical and social spaces, but also the cyberspace with a consequent increase in storage of data. Rules are being reformulated, with more complicated interactions among the various spaces, and this involves a more responsible knowledge which can guide towards helping make the proper decisions is artificial intelligence (AI).

AI involves data-collecting, analyzing and decision-making processes based on anything "artificial": that can be a machine, an algorithm, a computer program, a system or other. AI has been long considered as a sub-discipline of computer science, however, with its increasing applications to a large number of industries and research fields (e.g., energy, manufacturing, automotive, robotics, economy, philosophy) is nowadays considered a discipline on its own rights. Among the different fields, environmentally friendly and sustainable energy utilization is critically important for the whole world.

AI is becoming increasingly important for our energy industry and research, with great potential to redesign our future energy system. With the growing concerns of fossil fuel depletion and climate change, more and more countries started to support renewable energy development and utilization, and many of these projects are related to AI technology. The US Department of Energy announced totally $20 million funding for innovative research of AI in 2019 and established an Artificial Intelligence and Technology Office [1,2]. Detailed goals comprise improving grid resilience, increasing environmental sustainability, enabling smarter cities and speeding the discovery of new materials. Similarly, the cutting-edge research of energy and AI has been frequently highlighted in the Industrial Strategy Challenge Fund by the UK government, such as robotics applications in extreme energy activities like nuclear, offshore energy and deep mining [3]. In China, speeding up the development of the smart grid and the internet of energy, by deep integration of electricity market and AI technology, are key to the development of the nation's energy infrastructure as highlighted by the National Development and Reform Commission and National Energy Administration [4].

Besides the government authorities, combining energy and AI has been also widely accepted and adopted by industry. ExxonMobil used AI robots for hydrocarbon exploration and production to improve productivity and reduce the cost and worker risk [5]. China Petroleum and Chemical Corporation (Sinopec) worked with Huawei to construct smart factories which apply big data and machine learning in the refining process to improve efficiency and productivity [6]. Google decreased the cooling power consumption of its data center by 40% using the AI technology provided by DeepMind [7].

The past two decades have also witnessed the rapid rise of research investigations on how to apply AI to energy-related studies. As shown in Figure 1, the number of publications in Scopus with keywords "Energy + AI" has increased significantly, especially in the last ten years. Importantly, in years 2017, 2018 and 2019, the number of papers retrieved by keyword 'AI' in Scopus is 53752, 63093 and 77046, respectively, whilst the number retrieved by 'Energy + AI' is 14714, 18376 and 24496, respectively, indicating that more than a quarter of the researches on AI are related to energy.

AI will play a pivotal role in our future carbon-neutral energy system. As shown in Figure 2, AI will be the key enabling technology for the future smart energy systems, coupling different energy carriers (electricity, hydrogen and hydrocarbon fuels from wind, solar, nuclear and other renewable energy resources based on hydrogen production, carbon capture/reuse and other technologies) with the end-users (electrical appliances, transportation, heating, manufacturing, industry, and others). In such carbon-neutral energy system, energy diversity and localization must be realized, which can be underpinned by AI technologies for integrating infrastructure planning, energy forecasting, and intelligent control.

Beyond the system level, AI is everywhere when focusing on energy. It has been used for improving the design and manufacturing of energy-related devices and finding optimal energy materials, improving the safety of energy-use, as examples.

In this article, we present an overview of AI technologies and their applications in the energy arena. The related ethics, policy and security issues are also discussed. A perspective on the future energy revolution driven by AI is described. The first journal focusing on the cross-disciplinary area, Energy and AI, is also introduced.

Development of AI

The day when AI was born is generally recognized in the summer of 1956 [8]. A two-month long seminar, co-sponsored by young scholars John McCarthy, Marvin

Minsky, and others was held at Dartmouth College in the US. The seminar focused on the issue of using machines to simulate human intelligence, and the scholars used the term artificial intelligence for the first time. It was the first seminar on AI in human history, marking its birth. After the concept was proposed, the optimistic predictions of the influence of AI in the scientific community flourished. AI entered a golden age of more than 20 years.

After more than 20 years of rapid development, AI encountered the first technical bottlenecks, in 1973, when the report by the French mathematician James Lighthill based on informative data pointed out that many AI-related researches were meaningless, which led to the gradual cessation of funding. The second cold winter stemmed from the failure of Japanese fifth-generation intelligent computers in the 1980s. In 1984, Stanford University started to construct an encyclopedia containing common knowledge of humans, and hoped to achieve human-like reasoning. However, this development was obstructed by the knowledge acquisition problems. On the other hand, this promoted the development of data mining and machine learning [8, 9]. In fact, the bottlenecks of the 1970s and 1980s squeezed out the radical part of AI research, leading to a period of relatively steady development.

The knowledge-based expert system and deep learning have promoted the development of AI in different periods. A knowledge-based expert system is formed based on the intellect of experts and provides such knowledge to other people for solving problems. In the 1980s, many well-known expert systems were developed and applied around the world, such as the PROSPECTOR geological exploration expert system and ELAS drilling data analysis system [8].

Deep learning technology based on neural networks started shining in the field of AI in this century. In October 2012, the research team led by Professor Hinton began to apply the latest neural network technology to a large image recognition competition based on the ImageNet image library. Subsequently, the research and application of deep learning technology based on such neural networks became widely-recognized, and multiple application examples became well-known. Among them, the most famous iconic event was the 2016 man-machine game. Google's AlphaGo played against the top professional player Sedol Lee, which aroused the public attention on AI. AI also became increasingly important in the energy industry and research in recent years, including applications to smart grids, intelligent control of energy devices and systems, autopilot, and smart energy materials.

The year 2016 was the 60th anniversary of the concept of AI. In recent years, many countries in the world have regarded AI as a major platform to enhance national competitiveness and maintain national security, and the application of AI for energy is one of the top priorities. With the First International Conference on Energy and AI being held in Tianjin, China in January 2020, attracted more than 200 scholars from about 20 countries, we are entering a golden era for the joint research of Energy and

AI.

Energy and AI research

AI is an emerging technology already starting to transform the global economy and society. Energy is the sector where drastic changes are urgently needed for future sustainability and decarbonization, where AI will play an important role. The combination of the above two important areas will stimulate new research directions and trends, and will significantly change the research and innovation landscape in this field. Table 1 summarized the emerging research directions combining energy and AI, with representative works published in recent years [10-39]. It can be found that the energy and AI researches are truly interdisciplinary in nature and cover a wide range of subjects (from chemistry, physics, materials, engineering, to systems, finance, policy and social studies), technology readiness levels (TRLs) (from science discovery, proof of concept, to design optimization, operation, control, and security) and scales (from atoms, materials, devices, processes to the whole systems and societies).

Ethics and morality

Several ethics guidelines for AI development have been released over recent years, comprising normative principles and recommendations aimed to harness the disruptive potentials of new AI-enabled technologies, including their applications in the energy area [8]. With the expansion of its applications in recent years, both the positive and negative effects of AI have become increasingly remarkable. However, to date, the possible ethical consequences for combining energy and AI are still difficult to predict. Therefore, interdisciplinary researches at the interface between energy, AI, society and ethics is highly needed and particularly welcome by our journal: Energy and AI. We believe combing AI and energy may positively impact social development and human moral improvement in different ways, e.g., promoting the energy production process to be more ethical and socially beneficial. However, it may also cause ethical conflicts or dilemmas, such as data privacy, and moral responsibilities for autonomous decisions.

Policy and law

During the process of energy and AI research, development, application, and management, the rights, responsibilities and obligations of different moral subjects must be specified. The adverse consequences must be predicted and prevented. Therefore, policy and laws must be updated and in place to support that. We foresee that the development of AI and application in energy may pose challenges to existing law systems, and the constraints of policies and regulations on the development of AI industry may emerge very soon (e.g., data management and privacy, categorization of AI products, industrial standards, intellectual property protections).

Perspective: Energy revolution

Our energy system has evolved and developed drastically in the last decade, having supported substantial economic growth and social development. However, the imperative to limit climate change and achieve sustainable growth lead to the fact that the current energy system cannot be sustained. The International Renewable Energy Agency report ‘A roadmap to 2050’ stated that keeping the global temperature rise below 2 degrees Celsius is technically feasible, but to meet the goals, the global energy system must undergo a profound transformation, from one largely based on fossil fuels to one that enhances efficiency and is based on renewable energy [40].

The future energy system is of more complexities and uncertainties that can be difficult to handle by a human designer through conventional methods. This is largely induced by the implementation of renewable energy. There is a high desire to develop ‘AI designers’ who will be able to autonomously deliver optimal design solutions for future energy materials, devices, and systems to enable new products and services for future sustainable energy supplies, making them super-efficient, zero-loss, whilst maximizing their value creation.

The future energy system is often decentralized, posing difficulties in its control and real-time decision making. The digitalization of future energy systems will create new concepts and business model for energy generation and distribution. One typical example is the "virtual power plant" (VPP). The concept of using digital technology to aggregate electric vehicle (EV) batteries and other distributed energy sources, including smart appliances, into a digital platform to maximize the resources utilization. AI technology can collect data from these distributed resources and control them remotely.

The future of energy system will be diversified in terms of brands, usage plans and sources of energy. AI will also help in understanding energy consumers for creating a stable, scalable, and smart energy system. Consumer opinion and choices have a tremendous impact on the future energy business. AI has been proven successful capability in predicting and learning the consumer's habits, values, motivations, and personality, which therefore will help to further bolster the balancing and effectiveness of the energy system and allow for creating policies more effectively [40].

The journal: Energy and AI

The previous contents of this article show that a wealth of newly-built AI-related research methods as well as optimization strategies in many energy fields including energy policy, energy utilization, energy conversion and energy materials have been proposed. These excellent studies were published in many top-level journals in the energy field. However, there exists a vacancy on journals especially focusing on the cross-field between AI and energy research which is contrary to the popular development direction of current studies. There is no denying that establishing an appropriate journal not only benefits people who are engaged in this cross-field to meet their demands of consulting literatures and discovering the latest progress, but also for the consideration of potential researchers or readers to get acquainted with this cross field.

The new journal, Energy and AI, provides a fast and authoritative open access platform to disseminate the latest research progress in the cross-disciplinary area of energy and AI. The journal focuses on innovative applications of AI that address the critical challenges in energy systems, energy materials, energy chemistry, energy utilization & conversion, and energy & society, as well as other important pressing issues in energy research. The journal also considers papers on the development of bespoke AI technologies and methodologies for advancing energy, decarbonization and sustainable development, such as data-driven approaches, optimization algorithms and AI ethics. Energy and AI aims to become a leading journal for cutting-edge research at the interface between energy and AI. Papers purely focusing on a single aspect of energy or AI are not suitable for the journal. The journal publishes research, short communication, perspective and review articles.

Some typical focal points of the journal, but are not limited to, are already listed in Table 1, showing that there is a great potential for future submissions. We also use the Elsevier research performance tool, SciVal, to locate the most critical and popular research topics of the energy field in the last five years. As a first-level subject, energy totally includes 57 topic clusters, and among these, 13 are in the top 10% of worldwide topic clusters by prominence value [41]. We choose the top 8 citation impact topic clusters as the foothold which are listed in Table 2 [41]. It can be noticed that all the top citation impact topic clusters in Table 2 fall into the joint research areas in Table 1.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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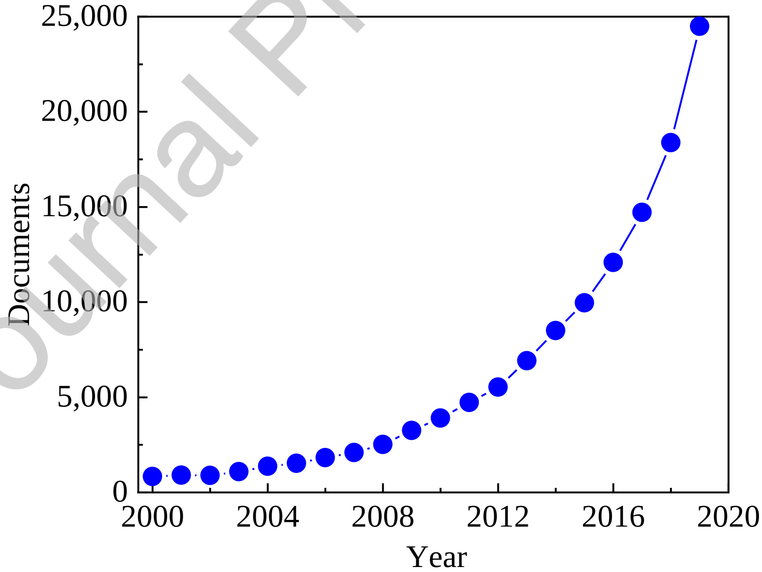

Figure 1. Number of publications in Scopus by searching “Energy + AI”

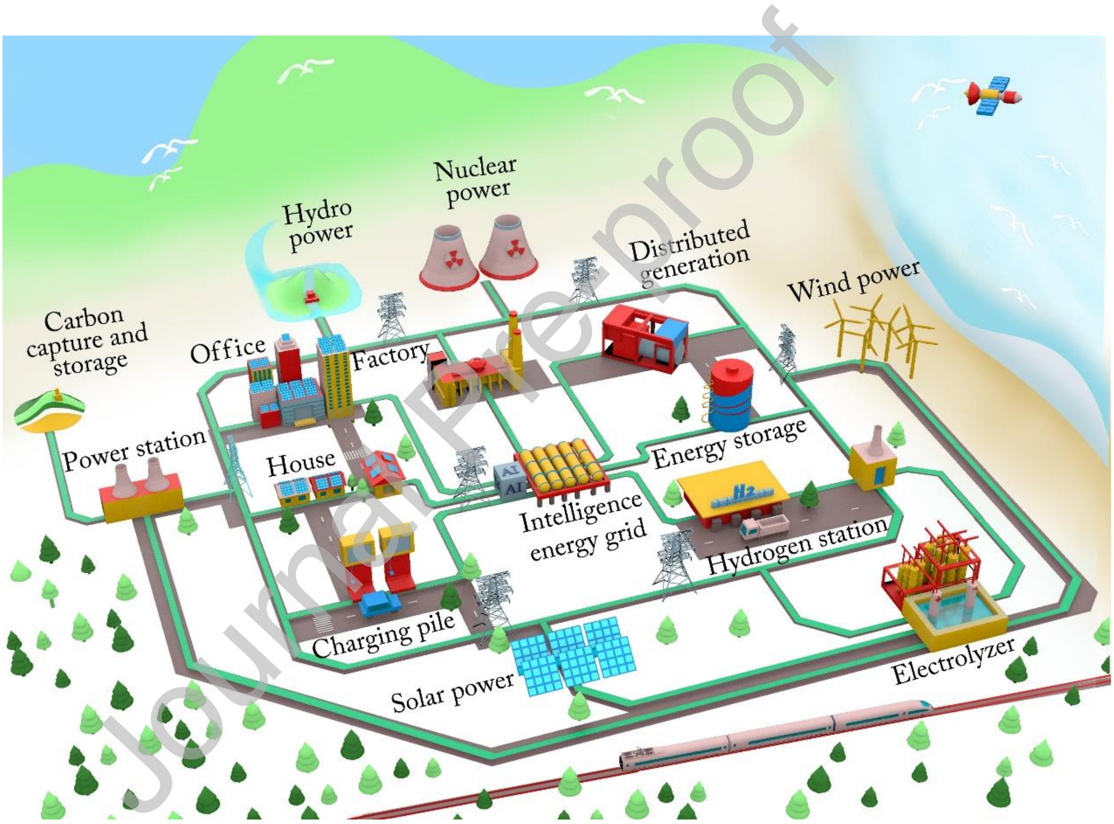

Figure 2. Carbon neutral energy system integrated with AI technology

Table 1. Typical joint areas of energy and AI and related researches and publications [10-39].

Joint areas of energy and AI	Related researches and publications
Automation of science discovery related to energy materials and chemistry	Proposing that high-performance computing, automation and machine learning accelerating the rate of materials discovery, freeing humans for more imagination and creative work [10]. Demonstrating applications of machine learning methods in key renewable energy technologies such as catalysis, batteries, solar cells and crystal discovery [11].
Digital twinning or big data analytics of complex energy processes/systems	Gathering energy data for over 750,000 buildings in the US for prediction of energy demand and other needs, discussing the usefulness and limitations and giving suggestions for such big-data analysis [12]. Developing geographic information system integrated data mining framework for estimating building energy use intensity [13].

Data-driven design of energy materials, devices, and systems	Data-driven learning of process-structure-property relationship in solution-grown tellurene, revealing the process factors effects on tellurene production [14]. Using machine learning techniques for predicting the efficiency of fullerene derivatives-based ternary organic solar cells at ternary blend design [15]. Developing a data-driven method to convert discrete representations of molecules to a multidimensional continuous representation for automatic chemical design [16].
Internet-of-things and cyber-physical energy systems	Using entropy theory for describing the distribution and powering of small electronics for internet-of-things [17]. Introducing potentials of cyber-physical integration of wind energy conversion systems [18]. Reviewing and assessing the role, impact and challenges of internet-of-things in transforming electric power and energy systems [19].
AI for human factors in energy-related activities	Reviewing AI-based short-term load demand forecasting techniques for smart grid and buildings based on load, weather, human and other data inputs [20].
Virtual reality applied to energy and environment	Developing a virtual reality integrated design approach for improving occupancy information integrity for closing building energy performance gap [21]. Developing a method for efficient utilization of building integrated photovoltaic systems under partial

	shading conditions in urban areas, by considering spatial structure and surrounding obstacles as a virtual reality environment [22].
Autonomous systems for energy efficiency maximalization	Summarizing experience gained from siting, design and dimensioning of hybrid power plants in autonomous insular power systems in Greece [23]. Investigating optimal energy and resource allocation for the downlink of an autonomous energy-harvesting base station, finding joint maximization of users' utilities and base station's revenue [24].
Hardware for data collections in energy systems	Developing a new sensor-based temperature data acquisition system for solar energy applications with flexibility and ease of changing the type of sensors and way of recording data [25]. Developing inexpensive open source devices for measuring and recording long-term indoor environmental and building operational data [26].
Data Science for energy applications	Extending statistical approach to effectively provide look-ahead forecasts for cooling and electricity demand load, forecasting load demands of a combined cooling, heating and power plant in California [27]. Assessing how dependent energy-related social practices (preparing food, washing, cleaning, washing clothes, watching TV and using computers) in household are in relation to time [28].
Hybrid data-driven and physical modelling for energy related problems	Optimizing proton exchange membrane fuel cell catalyst layer design based on data-driven surrogate modeling [29]. Diagnosing fault in solid oxide fuel cell power generation plants based on data-driven techniques

	[30].
Intelligent control of energy systems	Investigating the application of solar energy in public lighting for realizing street lighting sub-grid with positive yearly energy balance, optimizing intelligent central controller through data analysis [31]. Assessing the potential of photovoltaic hybrid systems to cover heating, ventilation and air conditioning loads in a grid-connected residential building through intelligent control [32].
AI, energy and society	Modeling heating and cooling loads by artificial intelligence for energy-efficient building design [33]. Predicting residential building energy consumption by neural network approach [34].
AI safety, reliability and ethics within energy applications	Reviewing AI related researches for renewable energy, giving future scopes [35].
AI for life-cycle assessment or energy and decarbonization roadmaps	Integrating AI and life cycle assessment for predicting energy output and environmental impacts of paddy production [36]. Combining AI and life cycle assessment for predicting output energy and environmental impacts of sugarcane production [37].
Energy robotics	Developing a highly sensitive, self-powered triboelectric auditory sensor for social robotics and hearing aids [38]. Proposing and evaluating potentials of hydrogen-powered, hydraulic free-piston pump

architecture for soft robotics [39].

Table 2. Top 8 citation impact topic clusters in the energy field by SciVal for 2015-2019 [41].

	Keywords of topic clusters
1	Secondary Batteries; Electric Batteries; Lithium Alloys
2	Electric Power Transmission Networks; Wind Power; Electric Power Distribution
3	Microbial Fuel Cells; Anaerobic Digestion; Bioreactors
4	Proton Exchange Membrane Fuel Cells (PEMFC); Electrocatalysts; Electrolytic Reduction
5	Biodiesel; Diesel Engines; Engine Cylinders
6	Solar Energy; Photovoltaic Cells; Solar Radiation
7	Electricity; Energy; Economics
8	Exergy; Heat Pump Systems; Rankine Cycle